Automated Building Information Models Reconstruction Using 2D Mechanical Drawings

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Abstract

One of the potential benefits of using Building Information Modeling (BIM) for Facility Management (FM) targets enhanced tradespeople performance, facilitated by efficient document management, equipment localization and visualization, and integration of building asset data. However, a major bottleneck towards achieving such a benefit is the lack of BIM. In addition, the owners or the facility managers do not want to invest in generating BIM because manually creating BIM for existing buildings is costly, time-consuming, and requires additional labors with specific skills to maintain. Therefore, the authors aim to build an automated Mechanical, Electrical, and Plumbing (MEP) BIM reconstruction framework that uses 2D building mechanical drawings. In this paper, the authors proposed a new method of generating 3D mechanical objects based on all available information in drawings, such as equipment schedules, symbols and spatial and topological relations amongst objects. The results have shown that the proposed approach could reconstruct more than 70% of the mechanical components among duct, VAV, AHU, FCU, BCU, diffuser, register, and sensor. Even though the authors were not able to achieve 100% success, it was shown that the proposed method reduced the time for generating the mechanical components and it is a major step towards the development of a BIM to support FM tasks associated with MEP components.

Keywords

Building information modeling (BIM) • Facility management (FM) • 3D reconstruction

60.1 Introduction

There are several reasons why building owners or facility managers currently have limited availability of BIMs to be used in FM. First, 80% of existing buildings were constructed based on 2D drawings and does not have BIM [1]. Second, not all MEP contractors are using BIM and hence the MEP BIM could not be delivered to the owner during handover [2, 3]. Third, manually creating BIM for existing buildings is costly, time-consuming, and requires additional labors with specific skills to maintain [4, 5]. Therefore, owners or the facility managers do not want to invest in such efforts [6].

All aspects described above signify a need to create BIMs for existing buildings in a cost- and time- efficient way. To address this need, a wide range of research studies have been conducted using 3D point cloud data (i.e., terrestrial laser-scanned data), photos, or building drawings to reconstruct BIMs but previous studies focused on generation of exterior enclosure or architectural models and did not generate MEP, which typically requires more frequent maintenance than the architectural and structure components in buildings.

Therefore, the authors have been aiming to build an automated MEP BIM reconstruction framework that uses 2D building mechanical drawings. The authors have previously explored graph-based searching methods to obtain closed-loops

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in building mechanical drawings which mostly indicates the duct components [7]. As a result, more than 80% of the ducts were recognized and reconstructed.

In addition, the authors investigated symbol recognition techniques, such as graph matching using semantic relationship [8], template matching using shape context [9], and network of geometric constraints [10], and proposed a vector-based symbol recognition approach to recognize and localize various symbols in mechanical drawings using the vectorial signature matching technique [11–13]. As a result, 75% recognition rate in average was obtained when symbol recognition test was conducted using the vectorial signature matching approach on six different drawings.

In this paper, the authors specifically discuss the developed object generating process which is related to the last step of the reconstruction framework. First, the authors identified all available information in drawings, such as information from equipment schedules, symbols and spatial and topological relations amongst objects that could be used for generating 3D mechanical objects. Second, reasoning rules for each type of relationships between symbols and surrounding parts were defined. Third, region searching technique was utilized to retrieve the related information from the symbols. Lastly, the result of the BIM reconstruction prototype is shown.

60.2 Method

60.2.1 Background Research

The as-built MEP BIM is needed for routine O&M tasks, to response to MEP-related emergencies [14], and to reduce the time for searching for historical records, site location, and related documents when a defect occurs [15]. Thus, many studies were conducted previously to generate BIM automatically as shown in the following Table 60.1.

However, to the best of the author's knowledge, none of the previous studies that attempted to reconstruct MEP BIM utilized the building mechanical 2D drawings along with the equipment schedule document. Thus, most of the previous

Table 60.1 Previous studies related to BIM reconstruction

References	Input	The reason of 3D reconstruction using the input	Output	3D reconstructed or recognized components
[16]	Terrestrial laser scan data	Manual 3D modeling is time-consuming and expensive	3D point model	Pipes were recognized
[17]	Images and point cloud	Images provide more info on the edges and help fix the bounds	As-built 3D model	Industrial site (pipe, equipment) reconstructed as cylinder and boxes
[18]	Terrestrial laser scan data, CAD database, and P&IDs	To use prior knowledge (scene, geometric, and topologic knowledge) from database (P&IDs)	3D model	Industrial instrumentation components
[19]	3D CAD design file and cluttered laser scan data	To automate the search and extraction of the object of interest	As-built pipe spool	Pipe spools (the prefabricated components of a piping system) were recognized
[20]	Laser scan data and pre-knowledge	Pre-knowledge (two ranges of diameter) was used to reduce computational time and cost	Text file (CAD layers)	Pipes and ducts were completely automatically reconstructed from raw point cloud data
[21]	Laser scan data	40% of the total modeling cost is spent on data-processing labor	3D pipeline model	Targeted to generate pipelines including pipes, elbows, and tee pipes

studies are limited to generating the as-built 3D model based on the geometric information. On the other hand, the building mechanical drawing set not only contains the layer of geometric information but the detailed property information in the equipment schedule document. Therefore, utilizing 2D drawings as inputs enables the reconstruction of mechanical equipment such as VAV box, AHU, FCU, etc. However, using 2D drawings and such documents also comes with challenges.

60.2.2 Challenges

Even though the symbols in 2D drawings could be recognized and localized with symbol recognition techniques, reconstructing 3D objects based on the obtained information is still a major challenge. Architectural walls can be simply extruded, but such extrusion method is not applicable for mechanical equipment since they have more complex geometry and connectivity with other components.

In previous studies, several researchers used a predefined 3D object database to link with the result of symbol recognition from drawings. However, based on the authors' case studies, generating these predefined objects (i.e., family objects) is the most time-consuming part of the entire manual modeling process. For example, it takes about 40–50 min to create a VAV unit in Revit. Thus, it is necessary to utilize all the available information from the 2D drawings for reconstructing the mechanical objects and minimize the process of creating the predefined 3D object database.

60.2.3 Available Information by Mechanical Components

In general, information of mechanical components can be obtained from four types of document in the building mechanical drawing set: the 2D drawings, symbol description document, schedule table document, and the section view drawings. The following Table 60.2 gives a summary of available geometric information by mechanical components.

The location of each mechanical components can be recognized through the symbol recognition process on 2D drawings. Recognizing the symbols in building mechanical drawings is essential but defining the relationship between the symbols and the surrounding parts is more important. For example, there can be multiple VAV boxes with different design models in the 2D drawings. Thus, it is required to search the surrounding areas to obtain the correct corresponding property information of each VAV boxes.

Table 60.2 Available information by major mechanical components

Component type	Geometry related information	Information source
Duct	• Physical shape • Dimension • Location	• 2D drawings
VAV	• VAV inlet size • Discharge duct opening size	• Schedule table document
	• Location	• 2D drawings
AHU	• Dimension (length, width, height, weight) • Detail of internal objects • Location (by floor level)	• Schedule table document
	• Location	• 2D drawings
FCU	• Location	• 2D drawings
BCU	• Location	• 2D drawings
Diffuser, register, and grille	• Neck size • Dimension	• Schedule table document
	• Location	• 2D drawings
Sensor	• Location	• 2D drawings

60.2.4 Relationship Between Symbols and the Surrounding Parts

In mechanical drawings, there are several parts such as ducts, annotations, and other symbols that surrounds a symbol. Thus, it is required to define the relationship between the symbols and the surrounding parts which could have meaningful relationship information for BIM reconstruction purpose.

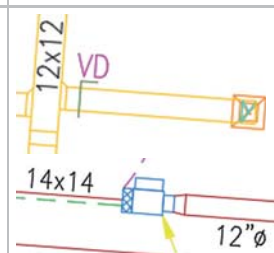
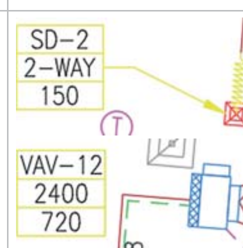
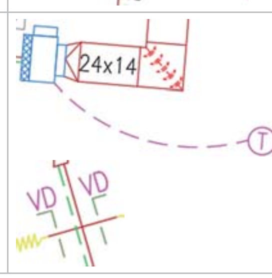
The authors have classified the relationship between symbols and the surrounding parts based on connectivity and location representation. The following Table 60.3 shows the three type of relationships that are presented in the building mechanical drawings.

Relationship between symbols and physically represented component. Many symbols in building mechanical drawings represent an equipment such as VAV, AHU, and diffuser or other components such as transition and damper. This means that symbols that appear in the 2D drawings have a high possibility of being connected to the duct. And this could be further classified into five type of relationships (Table 60.3). For example, there are equipment symbols that are connected at the end of the duct or connected in the middle of a duct. In addition, there are text information nearby regarding the physically represented component.

Relationship between symbols and annotation. Most annotation is connected to a particular symbol using an arrow but some annotation does not have arrows and is simply located near the symbol. Thus, two types of relationship are presented (Table 60.3). Annotations are objects drawn using the LEADER element in AutoCAD and usually placed in the 2D drawings to reference a certain equipment or indicate the dimension of such mechanical component.

Relationship between symbols and other symbols. Some equipment symbols such as VAV and FCU has temperature sensor symbols connected to it with a dashed line. This means that the equipment plays a role regarding the location of the temperature sensor. On the other hand, there are symbols that are placed near the other symbol. For example, the pink text VD (i.e., volume damper) is not connected to the other symbol but it is placed nearby and indicates that the green line symbols are volume dampers.

Table 60.3 Type of relationship between symbols and surrounding parts

Relationship between <>	Type of relationships	Examples
Symbols and physically represented component	• Equipment symbol that are connected at the end of the duct: diffuser, register, and grille • Equipment symbol that are connected in the middle of a duct: VAV, FCU • Component symbols that are connected in the middle of a duct: transition, damper • Component symbols that connects the end equipment and the duct: flexible duct • Surrounding text: dimension	
Symbols and annotation	• Annotation connected with arrow • Annotation connected without arrow	
Symbols and other symbols	• Symbols that indicate the serving location relationship: temperature sensor (T) • Symbols that describes what the other symbol is: volume damper (VD)	

60.2.5 Rules for Reasoning the Relationship

Based on the three type of relationship defined in Sect. 60.2.4, the authors established rules for reasoning each relationship. The following rules are utilized when searching the surrounding parts of the recognized symbols.

Rules for reasoning symbols and physically represented component. First, the dimension information indicates the dimension of the closest duct. But the location of the dimension information could vary. It could be placed above or below the duct or also could be inside the duct. Moreover, it could also have arrows when the surrounding area is compact. Second, the diffuser, register, and grille are located at the end of the duct. In some cases, there could be a flexible duct symbols between them. Third, equipment and components such as VAV box and volume damper are usually located somewhere in between the ducts and not at the end. Furthermore, the size of the inlet and outlet of an equipment should match with the connected duct size.

Rules for reasoning symbols and annotations. If there is an annotation of equipment reference, there is a related equipment symbol nearby. There could be an arrow between the equipment symbol and the equipment reference symbol. Note that there is a possibility that the end point of the arrow does not always align with the equipment symbol and could have disjoint draft errors.

Rules for reasoning symbols and other symbols. There is a dashed line between the temperature sensor and the equipment symbol. However, the carbon dioxide sensor sometimes has no connecting line. In this case, the symbol only provides the location information of the symbol.

60.3 Results

60.3.1 Vision of the Framework

By integrating all the process introduced in this paper and the previous paper [7], the authors proposed an automated BIM reconstruction framework (see Fig. 60.1). The proposed approach interprets three type of input data: 2D drawings, symbol description document, and equipment schedule.

Based on the input data and how the mechanical components are represented, it follows several different steps. If the component is a physically represented component, graph theory is utilized to find the minimum circuit that represents ducts [7]. On the other hand, if the components are represented as symbols, symbol recognition process is conducted using the vectorial signature matching technique.

Then using the retrieved information of the located symbols and the geometric information from the schedule table, the system checks whether if the obtained dimension information is sufficient enough or not to reconstruct BIM. If the information from the original input is not sufficient enough to create BIM, the system searches the web to find the most similar object as possible and retrieves the required information from the web. Finally, BIM can be reconstructed as Industry Foundation Classes (IFC) using the retrieved information from both input data and the web.

60.3.2 Prototype Implementation

Symbol recognition and surrounding region search. The purpose of surrounding region searching is to obtain the dimension information of the mechanical component of interest. Figure 60.2 shows the recognized and localized symbols in blue text labels. The surrounding area of each symbol is searched based on the location of the symbol. For example, equipment reference symbols (i.e., annotation symbol) are nearby the VAV box and supply diffuser symbols. First, the system retrieves the item code (e.g., VAV-03, SD-2, etc.) which is described in the equipment reference symbol. Then, the system further searches the equipment schedule document by using this item code.

If the dimension information is presented in the equipment schedule document, the system will retrieve the dimension information and use it for 3D reconstruction. If not, the object needs to be created based on the boundary information of the symbol itself or the retrieved information from the web.

BIM reconstruction. There is two type of dimension information that is utilized for the 3D reconstruction process. One type is in a form of 'Length x Width x Height' which is retrieved from the equipment schedule document or the web. The other type is in 'Min-x, Min-y, Max-x, Max-y' values which is also a form of a bounding box since some symbols do not

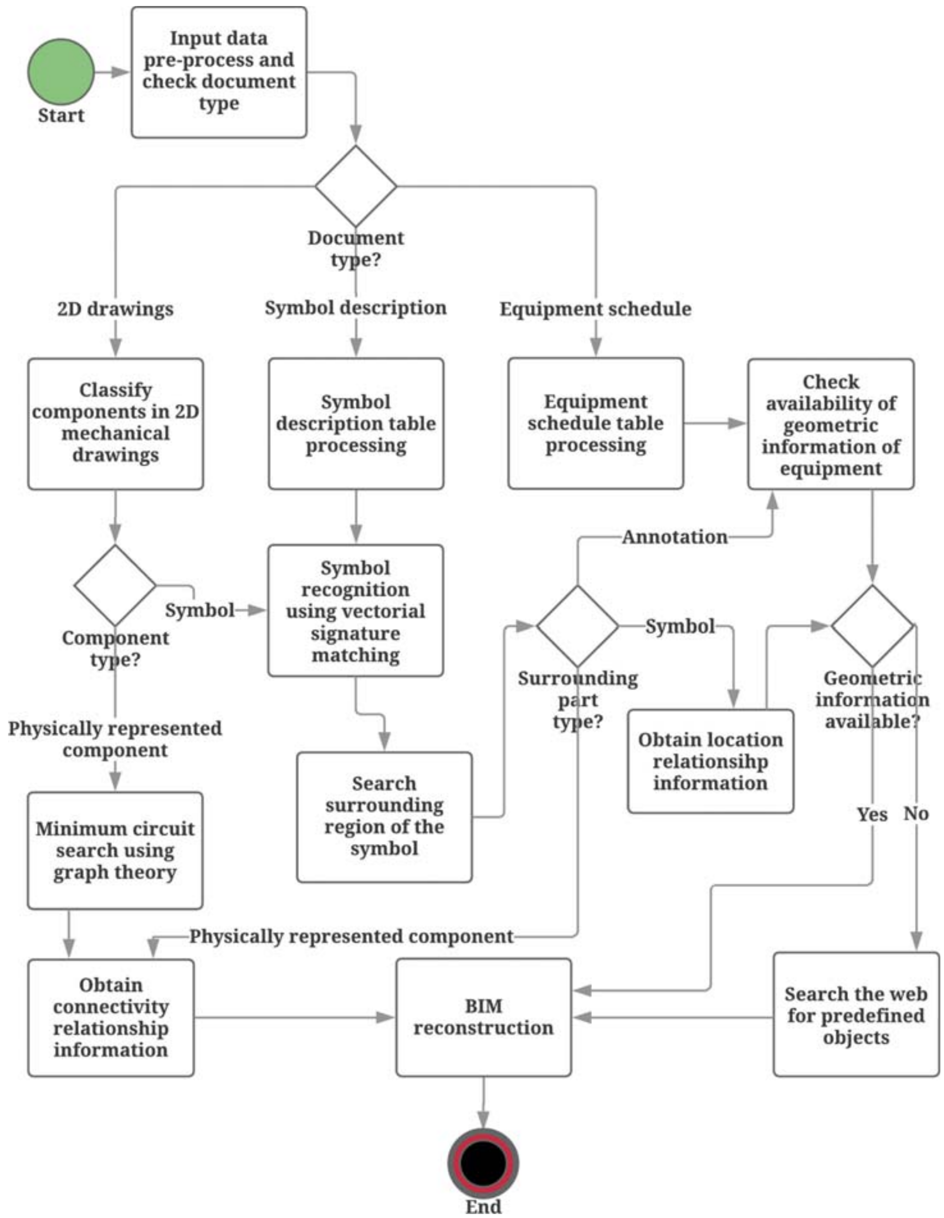


Fig. 60.1 MEP BIM reconstruction process diagram

have the dimension information in the equipment schedule document and require to use the boundary information of the symbol itself.

As a result, the mechanical equipment components are reconstructed as shown in Fig. 60.3. The left image of Fig. 60.3 is the 2D drawing that was used as input and the right image is the reconstructed BIM. The green dashed line indicates the corresponding symbols and reconstructed objects. Although not shown in the figure, note that the VAV object can contain additional information on top of geometric information such as the manufacturer, design model, air flow, and heating coil related information, et cetera which are retrieved from the equipment schedule document.

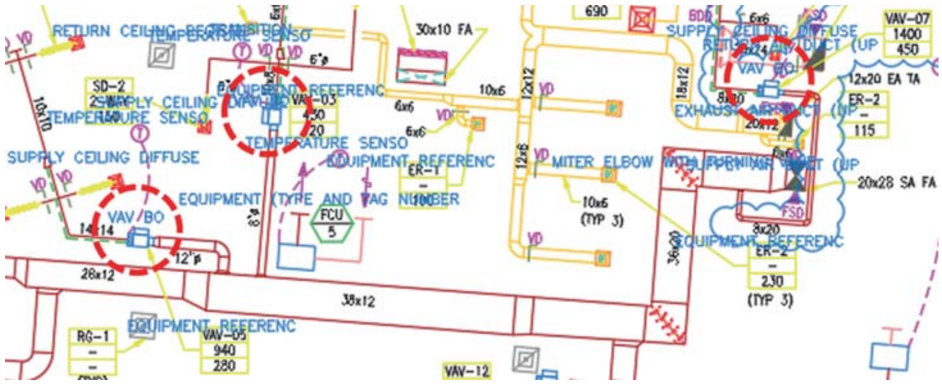


Fig. 60.2 Recognized symbols (VAV BOX highlighted in red dashed circle)

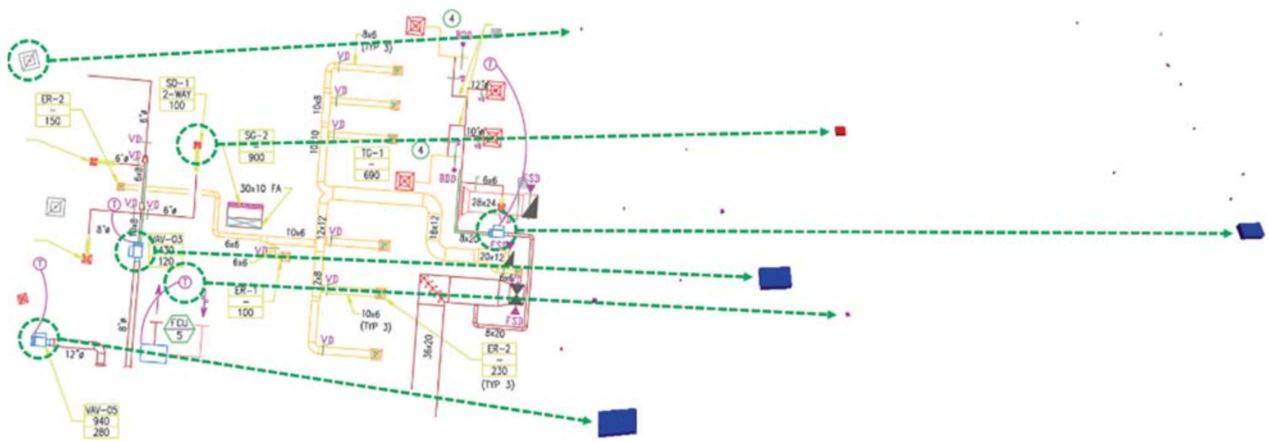


Fig. 60.3 BIM reconstruction result: input (left) and output (right)

60.4 Conclusion

In this paper, the authors have described the overall framework of the MEP BIM reconstruction process using the building mechanical 2D drawings, symbol description document, and the equipment schedule document. The main contribution of this paper is that it proposed a method that could process three type of input documents and connect the information to the mechanical component of interest. Moreover, the paper described the available information that is contained in the input documents along with the relationship and rules that needs to be considered for BIM reconstruction. As a result, 70% of the recognized symbols were reconstructed to BIM using the proposed framework. Future study would include the development of a more sophisticated approach to cover additional mechanical components for reconstruction and experiments on different building mechanical 2D drawing sets.

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